Ocean Engineering 160 (2018) 54–67

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Parametric FE modeling to predict hot spot stress concentrations of bird-beak SHS joints in offshore structures

Bin Cheng [a,b,*], Chen Li [b], Yu Lou [b], Xiaoling Zhao [c]

[a] State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
[b] Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
[c] Department of Civil Engineering, Monash University, Clayton, VIC, 3168, Australia

ARTICLE INFO

Keywords:
Square hollow section
Bird-beak joint
Stress concentration factor
Finite element model
Parametric study

ABSTRACT

Bird-beak square hollow section (SHS) joint is a new type of welded tubular joints that could be used in offshore structures. This paper presents a parametric finite element modeling strategy to predict the hot spot stress concentration factors (SCFs) of both diamond and square bird-beak SHS joints. ANSYS parametric design language (APDL) was employed by introducing three typical non-dimensional parameters (i.e., β, 2γ, τ) of SHS joints as main controlling variables, and the novel configurations of crown and saddle areas were accurately simulated during the modeling process. Tetrahedral-shaped solid elements were used so that the refined FE meshes generated from the map meshing match the requirements of extrapolation region that have been specified in IIW and CIDECT fatigue design guides. All extrapolating works were automatically implemented by pre-coded programs. The accuracy of constructed FE models has been validated by comparing with existing experimental data. The SCF variations with non-dimensional parameters were obtained by conducting parametric analysis, and the SCF comparisons between two types of bird-beak joints have been conducted. The proposed modeling approaches are applicable to bird-beak joints of different shapes and to the joints under various load cases and boundary conditions.

1. Introduction

Steel circular hollow sections (CHS) have been widely used in the offshore structures such as jacket-type oil platforms and jack-up rigs. These tubular joints containing weld intersections are prone to fatigue damages since the structures are cyclically loaded by sea waves (Saini et al., 2016; Liu et al., 2016; Ahmadi, 2016; Ahmadi et al., 2011). That's the reason why square hollow sections (SHS), whose flat surfaces would collect more lateral fluctuated loads, are much less adopted, despite that their intersecting lines at welded connections are simpler than CHS. The new-type bird-beak SHS joint is formed by rotating the members of a conventional SHS joint at 45° about their longitudinal axes. Correspondingly, two types of bird-beak SHS joints, that is, square bird-beak joint with chord rotated only and diamond bird-beak joint with chord and brace both rotated, are commonly considered. Fig. 1 shows the configurations of four types of tubular joints, where the characteristic crown and saddle areas in CHS joints are also found in bird-beak SHS joints. Such innovative bird-beak SHS joints are supposed to make the fabrication and welding easier than CHS joints and to assist in relieving lateral wave and wind loads, and therefore are suitable for the application into ocean engineering.

The strengths of bird-beak joints under static loads have been revealed by researchers including Ono et al. (1991; 1993; 1994), Ishida et al. (1993), Davies et al. (1996), Owen et al. (1996, 2001), Christitsas et al. (Chtistitas et al., 2007), Lei (2009), and Zhu and Liu (2012) to be higher than those of conventional joints with same non-dimensional parameters. Regarding the fatigue resistance, Ishida (1992) first carried out the fatigue tests of bird-beak T-joints in 1992 by considering the load case of brace axial force. Keizer et al. (Keizer et al., 2003; Keizer, 2003) investigated the stress concentration factors of diamond bird-beak joints under brace axial force. Recently, Tong et al. (2014, 2016) presented an experimental study on stress concentration factors for diamond bird-beak T-joints under axial force and in-plane bending on the brace, Cheng et al. (2014; 2015a; 2015b; 2018) carried out the researches to determine the strain/stress concentration factors of square bird-beak SHS T-joints under chord and brace axial forces.

As one of the most important parameters of fatigue resistance prediction for tubular joints, the structural hot spot stresses are commonly

* Corresponding author. Room A508, Ruth Mulan Chu Chao Building, 800 Dongchuan Road, Shanghai 200240, China.
E-mail address: cheng_bin@sjtu.edu.cn (B. Cheng).

https://doi.org/10.1016/j.oceaneng.2018.04.077
Received 10 August 2017; Received in revised form 17 January 2018; Accepted 20 April 2018

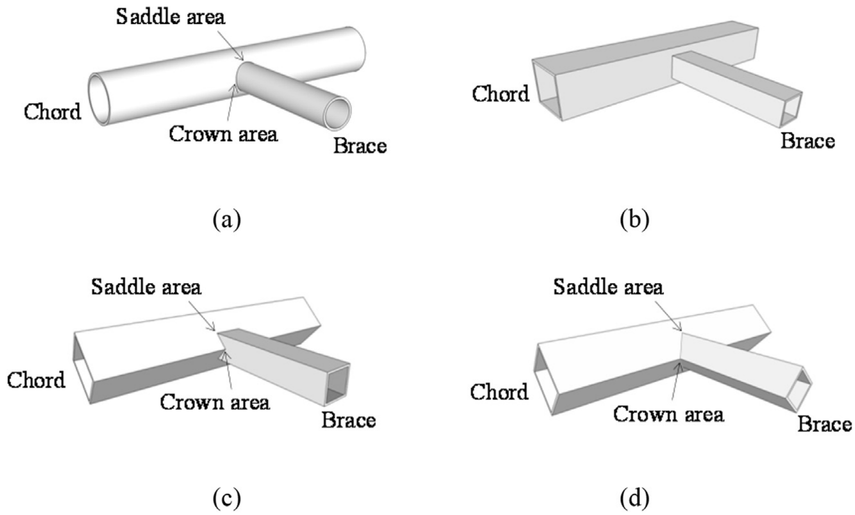

Fig. 1. Tubular joints: (a) CHS; (b) conventional SHS; (c) square bird-beak SHS; (d) diamond bird-beak SHS.

determined by using the stress concentration factor (SCF) formulae, which have been obtained from numerous parametric study of joints. The numerical modeling of bird-beak joints is fairly complicated due to the complex configurations around the welding junctions between the chord and the brace, especially when the parametric analysis is required. Therefore, this research presents advanced finite element modeling techniques for hot spot stress analysis of bird-beak SHS joints. Key aspects including common value ranges of non-dimensional parameters, geometries of fillet weld, specified hot spot locations, meshes in extrapolation regions, various load cases and boundary conditions, as well as automatic parametric calculation, will be considered in the modeling.

2. Bird-beak SHS joints

Both diamond and square bird-beak T-shape joints were employed in this study to illustrate the modeling process of such tubular connections with complicated welding conjunctions, as shown in Fig. 2. The lengths of chord and brace is respectively noted as L_0 and L_1, the sectional width and wall thickness of chord is noted as b_0 and t_0, and the sectional width and wall thickness of brace is noted as b_1 and t_1. Three non-dimensional parameters are defined as brace/chord width ratio $\beta = b_1/b_0$, chord wall slenderness ratio $2\gamma = b_0/t_0$, and brace/chord wall thickness ratio $\tau = t_1/t_0$, which are identical to the considerations for conventional SHS joints.

The welding junction of a bird-beak joint contains the so-called crown areas and saddle areas which are very common in circular hollow section (CHS) joints. As a result, high stress concentrations were certainly expected within these areas. By referring to the recommendations by Tong et al. (2014, 2016) and Cheng et al. (2014, 2015a), six saddle hot spots/lines (i.e., Sa-B, Sa-C and Sa-D on chord and Sa-E, Sa-F and Sa-A on brace) and six crown hot spots/lines (i.e., Cr-B, Cr-C and Cr-D on chord and Cr-E, Cr-F and Cr-A on brace) were selected for either diamond or square bird-beak joints, as shown in Fig. 2. The meshes of the model should be exactly consistent with these hot lines.

3. Aims and principles of modeling

3.1. Modeling aims

The FE modeling described in this paper is supposed to satisfy the aims as the following:

i. Bird-beak configurations, including the saddle and crown geometries, the sectional corners, as well as the weld dimensions around the brace-to-chord junction, can be accurately simulated in the model.
ii. The stress components perpendicular to weld toes within the extrapolation region at specified critical locations (i.e., hot spots) can be obtained from the model, so that the structural hot spot stresses at weld toes can be mathematically calculated.
iii. Typical load cases at member ends, including axial force, in-plane bending, and out-of-plane bending, can be properly considered.
iv. Parametric calculation considering common value ranges of three non-dimensional parameters (i.e., β, 2γ, τ) can be efficiently conducted, and stress outputs at specified locations can be automatically read from the FE models according to prescribed rules and then be automatically processed by mathematical softwares.

3.2. Modeling principles

Based on the aims, the following principles are adopted in the modeling:

i. The general finite element software ANSYS (ANSYS, 2016) is employed, and the ANSYS parametric design language (APDL) is used for the convenience of parametric analysis.
ii. Three typical non-dimensional parameters, i.e., brace/chord width ratio β, chord wall slenderness ratio 2γ, and brace/chord wall thickness ratio τ, are considered as the major controllable variables, and the other dimensional parameters are mainly determined by them. Corresponding to engineering applications, the value ranges of three non-dimensional parameters are taken as $0.3<\beta<1.0$ (diamond bird-beak), $0.3<\beta<1.3$ (square bird-beak), $10<2\gamma<25$ and $0.3<\tau<1.0$. In all finite element models, the chord wall thickness t_0 is originally defined as 10 mm, and subsequently other geometric dimensions (i.e., chord width b_0, brace width b_1, and brace wall thickness t_1) are determined by varying non-dimensional parameters (i.e., $b_0 = 2\gamma \cdot t_0$, $b_1 = \beta \cdot b_0$, $t_1 = \tau \cdot t_0$).
iii. SOLID95 elements each containing 20 nodes are used, and nonlinear printout at each integration point are pre-defined. The solid elements are efficient in constructing the complex geometries of SHS walls and fillet welds, especially for the crown and saddle areas where numerous spatial curves and spatial surfaces exist.
iv. Extrapolation regions near weld toes should be defined in strict accordance with the regulations in IIW (International Institute of Welding (IIW), 2008) and CIDECT (Zhao et al., 2000) fatigue